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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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Re application of:

Masao KASAHARA; Yasuyuki MURAKAMI

Serial No: Not assigned

Filed: November 1, 2000

For: ENCRYPTION METHOD, CRYPTOGRAPHIC COMMUNICATION METHOD,
CIPHERTEXT GENERATING DEVICE AND CRYPTOGRAPHIC COMMUNICATION
SYSTEM OF PUBLIC-KEY CRYPTOSYSTEM

Box PATENT APPLICATION
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Transmitted herewith for filing is the patent application identified above.

- ☒ 5 sheet(s) of drawings (☒ formal ☐ informal) is(are) enclosed.
- ☒ 40 page(s) of specification and 1 page(s) of abstract of the invention are enclosed.
- ☒ An assignment of the invention to MURATA MACHINERY LTD. and Masao KASAHARA ☒ is enclosed ☐ will follow.
- ☐ An associate power of attorney ☐ is enclosed ☐ will follow.
- ☐ A verified statement to establish small entity status under 37 C.F.R. 1.9 and 1.27 is enclosed.
- ☒ Declaration and Power of Attorney ☒ is enclosed ☐ will follow.
- ☒ A certified copies of Japanese Patent Application Nos. 11-314371 filed November 4, 1999 and 11-314372 filed November 4, 1999 from which priority is claimed under 35 U.S.C. § 119 is enclosed.
- ☒ IDS enclosed (☒ with 5 reference(s)).
- ☐ Preliminary Amendment is enclosed.
- ☒ Return postcard is enclosed.

CALCULATION OF FEES								
ITEM		TOTAL NO. OF CLAIMS		NO. OF CLAIMS OVER BASE	LG/SM \$ ENTITY FEE		\$ AMOUNT	\$ FEE
A	TOTAL CLAIMS FE E	22	-20	2	LG=\$18 SM=\$9	\$18	36	
B	INDEPENDENT CLAIMS FEE*	14	-3	11	LG=\$80 SM=\$40	\$80	880	
C	SUBTOTAL - ADDITIONAL CLAIMS FEE (ADD FINAL COLUMN IN LINES A + B)							916
D	MULTIPLE-DEPENDENT CLAIMS FEE				LARGE ENTITY FEE = \$270 SMALL ENTITY FEE = \$135		\$ 0	
E	BASIC FEE				LARGE ENTITY FEE = \$710 SMALL ENTITY FEE = \$355		\$ 710	
F	TOTAL FILING FEE (ADD TOTALS FOR LINES C, D, AND E)							\$ 1626
G	ASSIGNMENT RECORDING FEE						\$ 40	\$ 40
	*LIST INDEPENDENT CLAIMS 1, 5, 6, 8, 9, 10, 11, 12, 16, 17, 19, 20, 21, 22.							

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 - ☒ Any additional filing fees required under 37 C.F.R. 1.16
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Respectfully submitted,
HOGAN & HARTSON L.L.P.

By:

Louis A. Mok
Registration No. 22,585
Attorney for Applicant(s)

Date: November 1, 2000

500 South Grand Avenue, Suite 1900
Los Angeles, CA 90071
Telephone: (213) 337-6700
Facsimile: (213) 337-6701

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Masao KASAHARA et al.

Serial No: Not assigned

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For: ENCRYPTION METHOD, CRYPTOGRAPHIC COMMUNICATION
METHOD, CIPHERTEXT GENERATING DEVICE AND
CRYPTOGRAPHIC COMMUNICATION SYSTEM OF PUBLIC-KEY
CRYPTOSYSTEM

Art Unit: Not assigned

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I hereby certify that

- ☒ two copies of a letter of transmittal
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- ☒ 5 sheet(s) of formal drawings
- ☒ executed Declaration and Power of Attorney
- ☒ assignment of the invention to MURATA MACHINERY LTD. and Masao KASAHARA
- ☒ certified copies of Japanese patent application Nos. 11-314371 filed November 4, 1999 and 11-314372 filed November 4, 1999 from which priority is claimed in the subject case pursuant to 35 U.S.C. § 119
- ☒ Information Disclosure Statement with 5 references
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Date: November 1, 2000

Hogan & Hartson, LLP
500 South Grand Avenue, Suite 1900
Los Angeles, California 90071
Telephone: 213-337-6700
Facsimile: 213-337-6701

Darin Sutton
Name of person mailing papers

Signature

TITLE OF THE INVENTION

ENCRIPTION METHOD, CRYPTOGRAPHIC COMMUNICATION METHOD,
CIPHERTEXT GENERATING DEVICE AND CRYPTOGRAPHIC COMMUNICATION
SYSTEM OF PUBLIC-KEY CRYPTOSYSTEM

5

BACKGROUND OF THE INVENTION

The present invention relates to a public-key
cryptosystem encryption method and ciphertext generating
device for transforming a plaintext into a ciphertext by
10 using a public key, a cryptographic communication method and
cryptographic communication system using this encryption
method, and a memory product/data signal embodied in carrier
wave for recording/transmitting operation programs for these
methods.

15 In the modern society, called a highly
information-oriented society, based on a computer network,
important business documents and image information are
transmitted and communicated in a form of electronic
information. Such electronic information can be easily
20 copied, so that it tends to be difficult to discriminate its
copy and original from each other, thus bringing about an
important issue of data integrity. In particular, it is
indispensable for establishment of a highly information
oriented society to implement such a computer network that
25 meets the factors of "sharing of computer resources,"

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and a recipient perform cryptographic communications by possessing an identical common key. The sender encrypts a plaintext based on a secret common key and transmits the resultant ciphertext to the recipient, and then the
 5 recipient decrypts the ciphertext into the original plaintext by using this common key.

On the other hand, in a public-key cryptosystem, an encryption key and a decryption key are different from each other, and cryptographic communications are performed by
 10 encrypting a plaintext by the sender with the use of a publicized public key of the recipient and decrypting the resultant ciphertext by the recipient with the use of its own secret key. The public key is a key used for encryption and the secret key is a key used for decrypting the
 15 ciphertext transformed by the public key, and the ciphertext transformed by the public key can be decrypted only by the secret key.

As one scheme of public-key cryptosystem, a product-sum type encryption scheme has been known. In this encryption
 20 scheme, the sender as one of entities generates ciphertext $C = m_1c_1 + m_2c_2 + \dots + m_Kc_K$ by using plaintext vector $m = (m_1, m_2, \dots, m_K)$ obtained by dividing plaintext into K pieces and base vector $c = (c_1, c_2, \dots, c_K)$ as a public key, and the recipient as the other entity decrypts the ciphertext C into
 25 the plaintext vector m by using a secret key to obtain the

original plaintext.

Regarding the product-sum type cryptosystem using an operation on an integer ring, new schemes and attacking methods have been proposed one after another. In particular, development of encryption/decryption techniques capable of performing high-speed decryption has been desired so as to process a large quantity of information in a short time. Then, the present inventors proposed an encryption method and decryption method of the product-sum type cryptosystem, which enable high-speed decryption processing by expressing plaintext by using multi-adic numbers (Japanese Patent Application Laid-Open Nos. 2000-89668 and 2000-89669).

The following description will explain the encryption method and decryption method proposed in Japanese Patent Application Laid-Open No. 2000-89668 (hereinafter referred to as the "first conventional example"). The secret and public keys are prepared as follows.

- Secret key: $\{b_i\}$, $\{v_i\}$, P , w
- Public key: $\{c_i\}$

By multiplying a base-product $b_1b_2\cdots b_i$ by a random number term v_i , a base B_i is given as shown by (1) below.

$$B_i = v_i b_1 b_2 \cdots b_i \quad \cdots (1)$$

Here, v_i is set so that each B_i expressed by equation (1) has an almost equal size. However, the condition

$\gcd(v_i, b_{i+1})=1$ must be satisfied.

With the use of a random number w , the public key $\{c_i\}$ is found as shown by (2) below.

$$c_i \equiv wB_i \pmod{P} \quad \dots (2)$$

5 By performing the product-sum operation of messages $\{m_i\}$ obtained by dividing the plaintext into K pieces and the public keys $\{c_i\}$, the ciphertext C is obtained as shown by (3) below.

$$C = m_1c_1 + m_2c_2 + \dots + m_Kc_K \quad \dots (3)$$

10 Decryption processing is carried out as follows.

For the ciphertext C , an intermediate decrypted text M is found as shown by (4) below.

$$M \equiv w^{-1}C \pmod{P} \quad \dots (4)$$

This intermediate decrypted text M is specifically
15 given as equation (5), and it can be decrypted by a sequential decryption algorithm shown below.

$$M = m_1b_1v_1 + m_2b_1b_2v_2 + \dots + m_Kb_1b_2 \dots b_Kv_K \quad \dots (5)$$

[Sequential Decryption Algorithm]

20 Step 1

$$M_1 = M/b_1$$

$$m_1 = M_1v_1^{-1} \pmod{b_2}$$

Step i ($i = 2$ to $K-1$)

$$M_i = (M_{i-1} - m_{i-1}v_{i-1})/b_i$$

25 $m_i \equiv M_i v_i^{-1} \pmod{b_{i+1}}$

Step K

$$M_K = (M_{K-1} - m_{K-1} V_{K-1}) / b_K$$

$$m_K = M_K / V_K$$

Originally, such a public-key encryption scheme bases
 5 its security on the difficulty of factoring and the
 difficulty of solving a discrete logarithm problem, and
 various attacks against it have been proposed.

Moreover, the present inventors proposed a new type of
 public-key cryptosystem encryption method which bases its
 10 security on such a point that a set of public keys can be
 freely selected among a very large number of combinations of
 public keys (Japanese Patent Application No. 11-269407/1999,
 hereinafter referred to as the "second conventional
 example"). This scheme is a modified scheme of the above-
 15 mentioned first conventional example. In this scheme, a
 plurality of public keys produced from the products of
 integers and random number terms are prepared in advance for
 each divided plaintext obtained by dividing a plaintext, an
 arbitrary public key is selected for each divided plaintext
 20 among these prepared public keys, and a ciphertext is
 generated by using the selected public keys. The following
 description will explain the encryption method and
 decryption method proposed in this second conventional
 example.

25 The intermediate decryped text M during the first

5 However, m_1' is encoded to establish (7) below module J
for j given by adding $j \cdot \log_2 J$ -bit redundancy to message
(divided plaintext) m_1 , and the information indicating which
public key among later-described plurality of public keys is
to be selected for each divided plaintext is transmitted.

$$10 \quad m_i' \equiv j \pmod{J} \quad \cdots (7)$$

1, the set $\{b_1 b_2 \cdots b_{i v_i^{(j)}}\}$ provided by multiplying the base-product by a random number term is prepared as J pieces of public keys for each divided plaintext (each class).

20 and publicizes them. In other words, the products of the base-product and random number term shown in FIG. 1 are transformed as shown by (8) below, and the set $\{c_{ij}\}$ thereof is publicized.

25 A set of public keys which is randomly selected by an

entity as the sender is expressed as shown by (9) below. In this case, it is possible for the entity as the sender to select public keys in $J^K(\gg 1)$ ways.

[Eq. 1]

$$(c_1, j_1, c_2, j_2, \dots, c_K, j_K) \dots (9)$$

According to a set of the selected public keys shown in (9) above, the entity as the sender lets $m_i' \equiv j_i \pmod{J}$, and then generates the ciphertext C to the entity as the recipient as shown by (10) below.

[Eq. 2]

$$C = m_1' c_1, j_1 + m_2' c_2, j_2 + \dots + m_K' c_K, j_K \dots (10)$$

In order to decrypt the ciphertext C thus generated, the entity as the recipient predetermines the random number term $v_i^{(j)}$ of FIG. 1 as shown by (11) below.

$$v_i^{(j)} = w_{b,i} + r_i^{(j)} b_{i+1} \dots (11)$$

where each of $w_{b,i}, r_i^{(j)}$ is a random number.

Further, the entity as the recipient has $w_{b,i}^{-1}$ that satisfies (12) below as a secret key.

$$w_{b,i} \cdot w_{b,i}^{-1} \equiv 1 \pmod{b_{i+1}} \dots (12)$$

The decryption processing by the entity as the recipient is carried out as follows. An intermediate decrypted text M_0 is given as shown by (13) below.

[Eq. 3]

$$M_0 = m_1' b_1 v_1^{(j_1)} + m_2' b_1 b_2 v_2^{(j_2)} + \dots \\ + m_K' b_1 b_2 \dots b_K v_K^{(j_K)} \dots (13)$$

5 Therefore, decryption can be performed by the sequential decryption algorithm shown in (14) below. Incidentally, in (14), although b_{K+1} is a random number satisfying $m_K' < b_{K+1}$, it is not used as a base. In general, the random number term for j_i in step i is expressed as

10 shown by (15) below.

[Eq. 4] Sequential Decryption Algorithm

$$\left. \begin{array}{l} \text{Step 1} \\ M_1 = \frac{M_0}{b_1} \\ m_1' \equiv M_1 \cdot w_{b,1}^{-1} \pmod{b_2} \\ m_1' \equiv j_1 \pmod{J} \\ \text{Step } i \quad (i=2 \text{ to } K-1) \\ M_i = \frac{M_{i-1} - m_{i-1}' v_{i-1}^{(j_{i-1})}}{b_i} \\ m_i' \equiv M_i w_{b,i}^{-1} \pmod{b_{i+1}} \\ m_i' \equiv j_i \pmod{J} \\ \text{Step } K \\ M_K = \frac{M_{K-1} - m_{K-1}' v_{K-1}^{(j_{K-1})}}{b_K} \\ m_K' \equiv M_K w_{b,K}^{-1} \pmod{b_{K+1}} \end{array} \right\} \dots (14)$$

15

20

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$$v^{(j_i)} \dots (15)$$

In the decryption method proposed in the above-described second conventional example, since public keys are arbitrarily selected, i.e., since the entity as the sender freely selects public keys and generates ciphertext, the selection pattern of the public keys is unknown to attackers, and thus making it difficult to attack. Besides, the present inventors are further researching on a more practical encryption method.

BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a public-key cryptosystem encryption method, cryptographic communication method, ciphertext generating device and cryptographic communication system which are capable of achieving high-speed processing while ensuring security by free selection of public keys, and a memory product/data signal embodied in carrier wave for recording/transmitting operation programs for these methods.

According to a first aspect of the present invention, two public keys including a random number term therein are prepared for each divided plaintext in advance, a plaintext to be encrypted is divided into a plurality of 1-bit divided plaintexts, one public key is selected for each divided plaintext among the two public keys prepared, according to a bit pattern of the plurality of divided plaintexts, and a

when $s=1$, two public keys including a random number term therein (a public key list with two upper and lower rows) are prepared for each divided plaintext, one of the public keys is selected according to the bit data ("0", "1") of each divided plaintext, and all the selected public keys are added to generate the ciphertext. At this time, as an example, when the plaintext is "0", the public key of the upper row is selected, while when the plaintext is "1", the public key of the lower row is selected. With the second aspect, the ciphertext is generated simply by adding the public keys including a random number term therein, which are selected according to the bit data, and the encryption and decryption processing becomes extremely fast. The bit data of each divided plaintext used as a criterion to select a public key is unknown to the attackers and the selection pattern of the public keys can never be known, thereby achieving high security.

With the present invention, it is possible to achieve high-speed encryption/decryption processing while ensuring security by free selection of public keys, and the present invention can largely contribute to the development and realization of practical use of public-key encryption schemes.

The above and further objects and features of the invention will more fully be apparent from the following

FIG. 2 is a depiction showing a state in which an encryption scheme according to the first embodiment (first aspect) is used for information communications between entities A and B. The example shown in FIG. 2 illustrates a case where one of the entities, A, encrypts a plaintext X into a ciphertext C and transmits the ciphertext C to the other entity, B, via a communication path 1, and the entity B decrypts the ciphertext C into the original plaintext X.

The entity A as the sender is provided with a plaintext divider 2 for dividing the plaintext X into a plurality of 1-bit divided plaintexts, a public-key selector 3 for selecting a public key for each divided plaintext from a database 6 storing a public key list as described later, and an encryptor 4 for generating the ciphertext C by using the selected public keys and respective divided plaintexts. Besides, the entity B as the recipient is provided with a decryptor 5 for decrypting the transmitted ciphertext C into the original plaintext X. In this example, the issuer of the public key list is the entity B as the recipient, and the user of this public key list is the entity A as the sender.

Next, a specific technique will be explained. FIG. 3 is an illustration showing the public key list in the database 6 that stores a plurality of public keys for each divided plaintext in advance. FIG. 3 shows a public key

list in accordance with the supposition that a public key
for each divided plaintext is constructed by modular
transformation by (w_1, P_1) . In FIG. 3, K represents a
dividing number (class number) of the plaintext X , two
5 (upper row, lower row) public keys including a random number
term therein are prepared for each of K pieces of divided
plaintexts (for each class).

In the encryption method proposed in the second
conventional example, when $m_i=0$, the component $v_i^{(0)}$ of the
10 upper row of the public key list of FIG. 3 is selected,
while when $m_i=1$, the component $v_i^{(1)}$ of the lower row is
selected. Thus, when the technique is simply applied to the
encryption method of the second conventional example, a 0,
1-knapsack cryptosystem with an extremely low level of
15 security will result.

Then, in the first embodiment, it is determined which
row of the public keys in the public key list is to be
selected for each divided plaintext, according to a bit
pattern of a plurality of divided plaintexts. In other
20 words, after dividing the plaintext X into K pieces of 1-bit
divided plaintexts, selection information (x_1, x_2, \dots, x_K)
indicating which row of the public keys is to be selected is
determined for each divided plaintext, according to a bit
pattern of the K pieces of divided plaintexts $(m_1, m_2, \dots,$
25 $m_K)$. An algorithm for pre-coding the divided plaintexts to

entity A to the entity B via the communication path 1.
Then, the ciphertext C is decrypted into the original
plaintext X by the entity B.

The decryption processing by the decryptor 5 of the
entity B is carried out as follows.

An intermediate decrypted text M_1 is found as shown by
(18) below.

$$M_1 \equiv C \cdot w_1^{-1} \pmod{P_1} \quad \dots (18)$$

Let the selection information of the upper and lower
rows be $x_1 = 0$.

Next, with the use of the component $v_1^{(0)}$ of the upper
row, m_1 is found as shown by (19) below.

$$m_1 \equiv M_1 \cdot (v_1^{(0)})^{-1} \pmod{2} \quad \dots (19)$$

The next intermediate decrypted text M_2 is found as
shown by (20) below.

$$M_2 = M_1 - m_1 v_1^{(0)} \quad \dots (20)$$

Supposing that $x_2 = x_1 \text{ xor } m_1$, the next selection
information x_2 is found.

Then, by considering that the upper row is selected
when $x_2 = 0$ and the lower row is selected when $x_2 = 1$, m_2 is
found as shown by (21) below.

$$m_2 = M_2 \cdot (v_2^{(x_2)})^{-1} \pmod{2} \quad \dots (21)$$

Thereafter, in the same manner as for m_2 , the remaining
 m_3, \dots, m_k are decrypted.

In the first embodiment as described above, the first

base-product $v_1^{(1)}w_1$ in the lower row of FIG. 3 is not used for decryption of the pre-coding. Since the number of rows in the public key list is 2 rows ($J=2$), in the first embodiment, the length of the input plaintext becomes twice longer, but the weight index = (average weight)/(concatenate plaintext length) = $1/4$.

Incidentally, the above-described algorithm for pre-coding divided plaintexts to selection information is merely an example and, needless to say, it is possible to use another example of algorithm for determining the selection information of public keys according to the bit pattern of a plurality of divided plaintexts.

The following description will explain examples of the application of the first embodiment that achieve improved security.

(Application of Multi-Stage Encryption)

This is the application of the encryption method (the concept of multi-stage encryption) proposed in Japanese Patent Application No. 11-173338/1999 by the present inventors to the above-described encryption method, in which application ciphertext is generated by using the result of operating multi-stage modular-transformation by a plurality of random numbers on a public key selected for each divided plaintext. With respect to a base-product shown in FIG. 3, a plurality of sets (S sets) of a pair (w, P) of random

number w and prime number P are set, multiplication by the random numbers are performed over S stages, and the result is used as a public key. Hence, by applying the multi-stage encryption technique to the basic encryption scheme of the first embodiment, it is possible to establish a scheme that achieves higher security.

(Application of Product-Sum-Product Encryption)

This is the application of the encryption method (the concept of product-sum-product encryption) proposed in Japanese Patent Application No. 11-205381/1999 by the present inventors to the above-described encryption method, in which application ciphertext is generated by setting a plurality of product-sum terms of the divided plaintexts and public keys selected for each divided plaintext and combining the plurality of the product-sum terms in the forms of product or sum. A part of divided plaintexts obtained by dividing plaintext and public keys selected for each of that part of the divided plaintexts are used to generate plural sets of product-sum terms as shown by (16) above, and multiplication and/or addition of the generated plural sets of the product-sum terms are further performed to generate ciphertext. Thus, by applying the product-sum-product encryption technique to the basic encryption scheme of the first embodiment, it is possible to establish a scheme that achieves higher security.

As described in detail above, in the first embodiment, two public keys are prepared for each divided plaintext in advance, a plaintext to be encrypted is divided into a plurality of 1-bit divided plaintexts, one public key is
5 selected among the two public keys prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts, and a ciphertext is generated by using the plurality of divided plaintexts and selected public keys. It is therefore possible to achieve high-speed
10 encryption/decryption processing while ensuring security by free selection of public keys and to foster the development and practical use of the public-key encryption scheme.

Second Embodiment

The following description will explain a second
15 embodiment in which public keys are selected according to the bit data of a plurality of divided plaintexts.

FIG. 4 is a depiction showing a state in which an encryption scheme according to the second embodiment (second aspect) is used for information communications between the
20 entities A and B. Like FIG. 2, the example shown in FIG. 4 illustrates a case where one of the entities, A, encrypts a plaintext X into a ciphertext C and transmits the ciphertext C to the other entity, B, via a communication path 11, and the entity B decrypts the ciphertext C into the original
25 plaintext X.

The entity A as the sender is provided with a plaintext divider 12 for dividing the plaintext X into a plurality of divided plaintexts, a public-key selector 13 for selecting a public key for each divided plaintext from a database 16 storing a public key list, and an encryptor 14 for generating the ciphertext C by using the selected public keys. Besides, the entity B as the recipient is provided with a decryptor 15 for decrypting the transmitted ciphertext C into the original plaintext X. In this example, the issuer of the public key list is the entity B as the recipient, and the user of this public key list is the entity A as the sender.

Next, a specific technique will be explained. Note that the following explanation is given by illustrating an example in which $s = 1$, i.e., each divided plaintext is one bit and two public keys are provided for selection with respect to each divided plaintext. FIG. 3 is an illustration showing the public key list in the database 16 that stores two public keys for each divided plaintext in advance. FIG. 3 shows a public key list in accordance with the supposition that a public key for each divided plaintext is constructed by modular transformation by (w_i, P_i) . In FIG. 3, K represents a dividing number (class number) of the plaintext X, two (upper row, lower row) public keys including a random number term therein are prepared for each

of K pieces of divided plaintexts (for each class).

Besides, the random number $v_i^{(0)}$ and random number $v_i^{(1)}$ in FIG. 3 satisfy (22) and (23) below, respectively.

$$v_i^{(0)} \equiv 0 \pmod{2} \quad \dots (22)$$

$$v_i^{(1)} \equiv 0 \pmod{2} \quad \dots (23)$$

After dividing the plaintext X into K pieces of 1-bit divided plaintexts, the entity A selects a public key according to the bit data of each of the divided plaintexts. In other words, when the divided plaintext is $m_i = 0$, a public key of the upper row, i.e., the base-product $2^{i-1}v_i^{(0)}$, is selected, while when the divided plaintext is $m_i = 1$, a public key of the lower row, i.e., the base-product $2^{i-1}v_i^{(1)}$, is selected. By sequentially adding the selected public keys, the ciphertext C to the entity B is generated as shown by (24) below.

$$C = v_1^{(t1)}w_1 + 2v_2^{(t2)}w_1 + \dots + 2^{K-1}v_K^{(tK)}w_1 \quad \dots (24)$$

$$(t1, t2, \dots, tK = 0 \text{ or } 1)$$

For example, when the divided plaintexts are $(m_1, m_2, m_3, m_4, m_5) = (0, 1, 0, 1, 0)$, the ciphertext C to the entity B is generated as shown by (25) below.

$$C = v_1^{(0)}w_1 + 2v_2^{(1)}w_1 + 2^2v_3^{(0)}w_1 + 2^3v_4^{(1)}w_1 + 2^4v_5^{(0)}w_1 \quad \dots (25)$$

The ciphertext C thus generated is transmitted from the entity A to the entity B via the communication path 11. Then, the ciphertext C is decrypted into the original plaintext X by the entity B.

The decryption processing by the decryptor 15 of the entity B is carried out as follows.

An intermediate decrypted text M_1 is found as shown by (26) below.

$$5 \quad M_1 \equiv C \cdot w_1^{-1} \pmod{P_1} \quad \dots (26)$$

Here, it is apparent that the intermediate decrypted text M_1 is expressed as shown by (27) below. Here, however, (28) shown below must be satisfied.

[Eq. 5]

$$10 \quad M_1 = v_1^{(m_1)} + 2 v_2^{(m_2)} + 2^2 v_3^{(m_3)} \dots + 2^{K-1} v_K^{(m_K)} \quad \dots (27)$$

$$|2^{i-1} v_i^{(m_i)}| \geq K + 64 \quad \dots (28)$$

Therefore, decryption can be performed by a decryption algorithm shown in (29) below. It will be appreciated that this decryption algorithm is extremely simplified.

[Eq. 6]

Decryption Algorithm

$$\begin{array}{l}
 \text{Step 1} \\
 \left. \begin{array}{l}
 \text{when } M_1 \equiv 0 \pmod{2}, \text{ decryption of } m_1 = 0 \\
 \text{when } M_1 \equiv 1 \pmod{2}, \text{ decryption of } m_1 = 1
 \end{array} \right\} \\
 \\
 \text{Step } i \text{ (} i=2 \text{ to } K \text{)} \\
 M_i = \frac{M_{i-1} - v_{i-1}^{(m_{i-1})}}{2} \\
 \left. \begin{array}{l}
 \text{when } M_1 \equiv 0 \pmod{2}, \text{ decryption of } m_1 = 0 \\
 \text{when } M_1 \equiv 1 \pmod{2}, \text{ decryption of } m_1 = 1
 \end{array} \right\} \dots (29)
 \end{array}$$

The following description will explain the characteristics of the encryption scheme of the second embodiment by mainly discussing the comparison between this encryption scheme and a 0, 1-knapsack cryptosystem which is very close to this. There is a notable difference between the encryption scheme of the second embodiment and the conventional knapsack cryptosystem in that the encryption scheme of the second embodiment does not have $\sum m_i c_i$ form, i.e., is not of product-sum type but is of addition type.

In the scheme of the second embodiment, the weight index = 1/2 for the concatenate plaintext. For this sense, it would be considered that the scheme of the second embodiment is strengthened against concatenate attacks. The scheme of the second embodiment has the following significant characteristics in comparison with the conventional 0, 1-knapsack cryptosystem.

In the scheme of the second embodiment, as the sum of ciphertext C shown in (30) below based on the public keys (c_1, c_2, \dots, c_k) corresponding to the upper row of FIG. 3 and ciphertext C' shown in (31) below based on the public keys $(c_1', c_2', \dots, c_k')$ corresponding to the lower row of FIG. 3, ciphertext C^s is given as shown by (32) below.

security.

(Application of Multi-Stage Encryption)

This is the application of the encryption method (the concept of multi-stage encryption) proposed in Japanese Patent Application No. 11-173338/1999 by the present inventors to the above-described encryption method, in which application ciphertext is generated by using the result of operating multi-stage modular-transformation by a plurality of random numbers on a public key selected for each divided plaintext. With respect to a base-product shown in FIG. 3, a plurality of sets (S sets) of a pair (w, P) of random number w and prime number P are set, multiplication by the random numbers are performed over S stages, and the result is used as a public key. Hence, by applying the multi-stage encryption technique to the basic encryption scheme of the second embodiment, it is possible to establish a scheme that achieves higher security.

(Application of Product-Sum-Product Encryption)

This is the application of the encryption method (the concept of product-sum-product encryption) proposed in Japanese Patent Application No. 11-205381/1999 by the present inventors to the above-described encryption method, in which application ciphertext is generated by setting a plurality of sum terms obtained by adding a plurality of selected public keys and combining a plurality of the sum

terms in the form of product and/or sum. Plural sets of sum terms as shown by (24) above are generated with the use of a plurality of public keys selected according to the bit data of each divided plaintext, and multiplication and/or

5 addition of the generated plural sets of the sum terms are further performed to generate ciphertext. Thus, by applying the product-sum-product encryption technique to the basic encryption scheme of the second embodiment, it is possible to establish a scheme that achieves higher security.

10 Incidentally, in the above-described example, while the case where two public keys are provided for selection with respect to each divided plaintext ($s=1$) has been explained, it is possible to expand the application to the case where $b_i=2^s$ (s : natural number no less than 2) by using a random

15 number as shown by (36) below that satisfies (35) below. For example, when $s=2$, four public keys are prepared for each divided plaintext, a plaintext is divided into 2-bit divided plaintexts, one public key is selected for each divided plaintext among the four public keys according to

20 the bit data of each divided plaintext, and a ciphertext is generated in the form of sum of all of the selected public keys.

[Eq. 9]

$$v_i^{(m_i)} \equiv m \pmod{2^s} \quad \dots (35)$$

$$v_i^{(m_i)} \quad \dots (36)$$

5 As described in detail above, in the second embodiment, 2^s public keys including a random number term therein are prepared for each divided plaintext in advance, a plaintext to be encrypted is divided into a plurality of s-bit divided plaintexts, one public key is selected for each divided
10 plaintext among the 2^s public keys prepared for each divided plaintext, according to the bit data of each divided plaintext, and a ciphertext is generated by using the selected public keys. It is therefore possible to achieve high-speed encryption/decryption processing while ensuring
15 security by free selection of public keys and to foster the development and practical use of the public-key encryption scheme.

Further, while the above-described examples are illustrated for the cryptographic communication system,
20 needless to say, it is possible to apply the encryption methods of the first and second embodiments of the present invention to the case where a ciphertext is by encrypting a plaintext and the generated ciphertext is simply recorded.

Next, examples of a memory product and transmission
25 medium of the present invention will be explained. FIG. 5

is an illustration showing the structures of embodiments of the memory product of the present invention. The programs exemplified here include a process for selecting a public key for each divided plaintext among a plurality of public keys stored in the database 6 (or 16) in advance, according to the data pattern of a plurality of divided plaintexts (or the bit data of each divided plaintext), and a process for generating ciphertext by using the selected public keys and divided plaintexts (or by using the selected public keys), or include a process for decrypting the ciphertext thus generated according to the above-described decryption algorithm, and are recorded in the memory product explained below. Besides, a computer 20 is provided for each entity.

In FIG. 5, a memory product 21 to be on-line connected to the computer 20 is constructed by, for example, a WWW (World Wide Web) server computer installed at a distant point from the installation position of the computer 20, and a program 21a as mentioned above is stored in the memory product 21. The program 21a read from the memory product 21 through a transmission medium 24 such as a communication line controls the computer 20 to generate the ciphertext C, or decrypt the ciphertext C into the original plaintext X.

A memory product 22 provided inside the computer 20 is constructed by, for example, a hard disk drive or ROM installed in the computer 20, and a program 22a as mentioned

CLAIMS

1. An encryption method for generating a ciphertext from divided plaintexts obtained by dividing a plaintext to be encrypted, comprising the steps of:

dividing a plaintext to be encrypted into a plurality of 1-bit divided plaintexts;

selecting one public key for each divided plaintext among two public keys which include therein a random number term and are prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts; and

generating a ciphertext by using the plurality of divided plaintexts and selected public keys.

2. The encryption method as set forth in claim 1, wherein the ciphertext is generated by adding a plurality of products of the respective divided plaintexts and correspondingly selected public keys.

3. The encryption method as set forth in claim 1, wherein the ciphertext is generated by multiplying and/or adding a plurality of product-sum terms obtained by adding a plurality of products of the respective divided plaintexts and correspondingly selected public keys.

4. The encryption method as set forth in claim 1, wherein the ciphertext is generated by using a result of operating multi-stage modular-transformation by a plurality

of random numbers on the selected public keys.

5. A cryptographic communication method for communicating information by a ciphertext between entities, comprising the steps of:

dividing at a first entity a plaintext to be encrypted
into a plurality of 1-bit divided plaintexts;

selecting at the first entity one public key for each divided plaintext among two public keys which include therein a random number term and are prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts;

generating at the first entity a ciphertext by using the plurality of divided plaintexts and selected public keys and transferring the ciphertext to the second entity; and

decrypting at the second entity the transferred ciphertext into a plaintext.

6. A device for generating a ciphertext by using divided plaintexts obtained by dividing a plaintext to be encrypted and public keys, comprising:

a database storing two public keys including a random number term therein for each divided plaintext in advance;

a divider dividing a plaintext to be encrypted into a plurality of 1-bit divided plaintexts;

a selector selecting one public key for each divided
plaintext among the two public keys, according to a bit

P

pattern of the plurality of 1-bit divided plaintexts; and
 an encryptor generating a ciphertext by using the
 plurality of divided plaintexts and selected public keys.

7. A cryptographic communication system for
 communicating information by a ciphertext between entities,
 comprising:

an encryptor generating a ciphertext from a plaintext
 by using the encryption method of claim 1;

a communication path transmitting the generated
 ciphertext from a first entity to a second entity; and

a decryptor decrypting the transmitted ciphertext into
 a plaintext.

8. A computer memory product having computer readable
 program code means for causing a computer to generate a
 ciphertext by using divided plaintexts obtained by dividing
 a plaintext to be encrypted and public keys, said computer
 readable program code means comprising:

program code means for causing the computer to divide a
 plaintext to be encrypted into a plurality of 1-bit divided
 plaintexts;

program code means for causing the computer to select
 one public key for each divided plaintext among two public
 keys which include therein a random number term and are
 prepared for each divided plaintext, according to a bit
 pattern of the plurality of divided plaintexts; and

program code means for causing the computer to generate a ciphertext by using the plurality of divided plaintexts and selected public keys.

9. A computer memory product having computer readable program code means for causing a computer to decrypt a ciphertext generated by using a plurality of 1-bit divided plaintexts obtained by dividing a plaintext and a plurality of public keys selected in such a manner that one public key is selected for each divided plaintext among two public keys which include therein a random number term and are prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts, said computer readable program code means comprising:

program code means for causing the computer to sequentially decrypt the divided plaintexts while identifying the selected public keys.

10. A computer data signal embodied in a carrier wave for transmitting a program, the program being configured to cause a computer to generate a ciphertext by using divided plaintexts obtained by dividing a plaintext to be encrypted and public keys, comprising:

a code segment for causing the computer to divide a plaintext to be encrypted into a plurality of 1-bit divided plaintexts;

a code segment for causing the computer to select one

00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

public key for each divided plaintext among two public keys which include therein a random number term and are prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts; and

a code segment for causing the computer to generate a ciphertext by using the plurality of divided plaintexts and selected public keys.

11. A computer data signal embodied in a carrier wave for transmitting a program, the program being configured to cause a computer to decrypt a ciphertext generated by using a plurality of 1-bit divided plaintexts obtained by dividing a plaintext and a plurality of public keys selected in such a manner that one public key is selected for each divided plaintext among two public keys which include therein a random number term and are prepared for each divided plaintext, according to a bit pattern of the plurality of divided plaintexts, comprising:

a code segment for causing the computer to sequentially decrypt the divided plaintexts while identifying the selected public keys.

12. An encryption method for generating a ciphertext from divided plaintexts obtained by dividing a plaintext to be encrypted, comprising the steps of:

dividing a plaintext to be encrypted into a plurality of s-bit (s: natural number) divided plaintexts;

selecting one public key for each divided plaintext among 2^s public keys which include therein a random number term and are prepared for each divided plaintext, according to bit data of each divided plaintext; and

generating a ciphertext by using the selected public keys.

13. The encryption method as set forth in claim 12, wherein the ciphertext is generated by adding the selected public keys.

14. The encryption method as set forth in claim 12, wherein the ciphertext is generated by multiplying and/or adding a plurality of sum terms obtained by adding the selected public keys.

15. The encryption method as set forth in claim 12, wherein the ciphertext is generated by using a result of operating multi-stage modular-transformation by a plurality of random numbers on the selected public keys.

16. A cryptographic communication method for communicating information by a ciphertext between entities, comprising the steps of:

dividing at a first entity a plaintext to be encrypted into a plurality of s -bit (s : natural number) divided plaintexts;

selecting at the first entity one public key for each divided plaintext among 2^s public keys which include therein

a communication path transmitting the generated ciphertext from a first entity to a second entity; and

a decryptor decrypting the transmitted ciphertext into a plaintext.

19. A computer memory product having computer readable program code means for causing a computer to generate a ciphertext based on divided plaintexts obtained by dividing a plaintext to be encrypted and public keys, said computer readable program code means comprising:

program code means for causing the computer to divide a plaintext to be encrypted into a plurality of s-bit (s: natural number) divided plaintexts;

program code means for causing the computer to select one public key for each divided plaintext among 2^s public keys which include therein a random number term and are prepared for each divided plaintext, according to bit data of each divided plaintext; and

program code means for causing the computer to generate a ciphertext by using the selected public keys.

20. A computer memory product having computer readable program code means for causing a computer to decrypt a ciphertext generated by using a plurality of public keys selected in such a manner that one public key is selected for each of a plurality of s-bit divided plaintexts obtained by dividing a plaintext among 2^s (s: natural number) public

Figure 1 consists of 12 subplots, labeled (a) through (l), each showing a time course of a different physiological parameter. The x-axis for all plots represents time, with a baseline period followed by a 10-minute intervention period. The y-axis for each plot represents the value of the parameter. The parameters are: (a) HR (b/min), (b) SBP (mmHg), (c) DBP (mmHg), (d) MAP (mmHg), (e) SV (L/min), (f) CO (L/min), (g) SVI (ml/m²), (h) COI (L/min/m²), (i) SVR (dyne/cm²), (j) COVR (L/min/cm²), (k) SVR (dyne/cm²), and (l) COVR (L/min/cm²). The plots show that during the intervention period, HR, SBP, DBP, MAP, SV, CO, SVI, and COI generally decrease or stabilize, while SVR and COVR remain relatively stable or show a slight increase.

keys which include therein a random number term and are prepared for each divided plaintext, according to bit data of each divided plaintext, said computer readable program code means comprising:

program code means for causing the computer to sequentially decrypt the divided plaintexts while identifying the selected public keys.

21. A computer data signal embodied in a carrier wave for transmitting a program, the program being configured to cause a computer to generate a ciphertext based on divided plaintexts obtained by dividing a plaintext to be encrypted and public keys, comprising:

a code segment for causing the computer to divide a plaintext to be encrypted into a plurality of s-bit (s: natural number) divided plaintexts;

a code segment for causing the computer to select one public key for each divided plaintext among 2^s public keys which include therein a random number term and are prepared for each divided plaintext, according to be data of each divided plaintext; and

a code segment for causing the computer to generate a ciphertext by using the selected public keys.

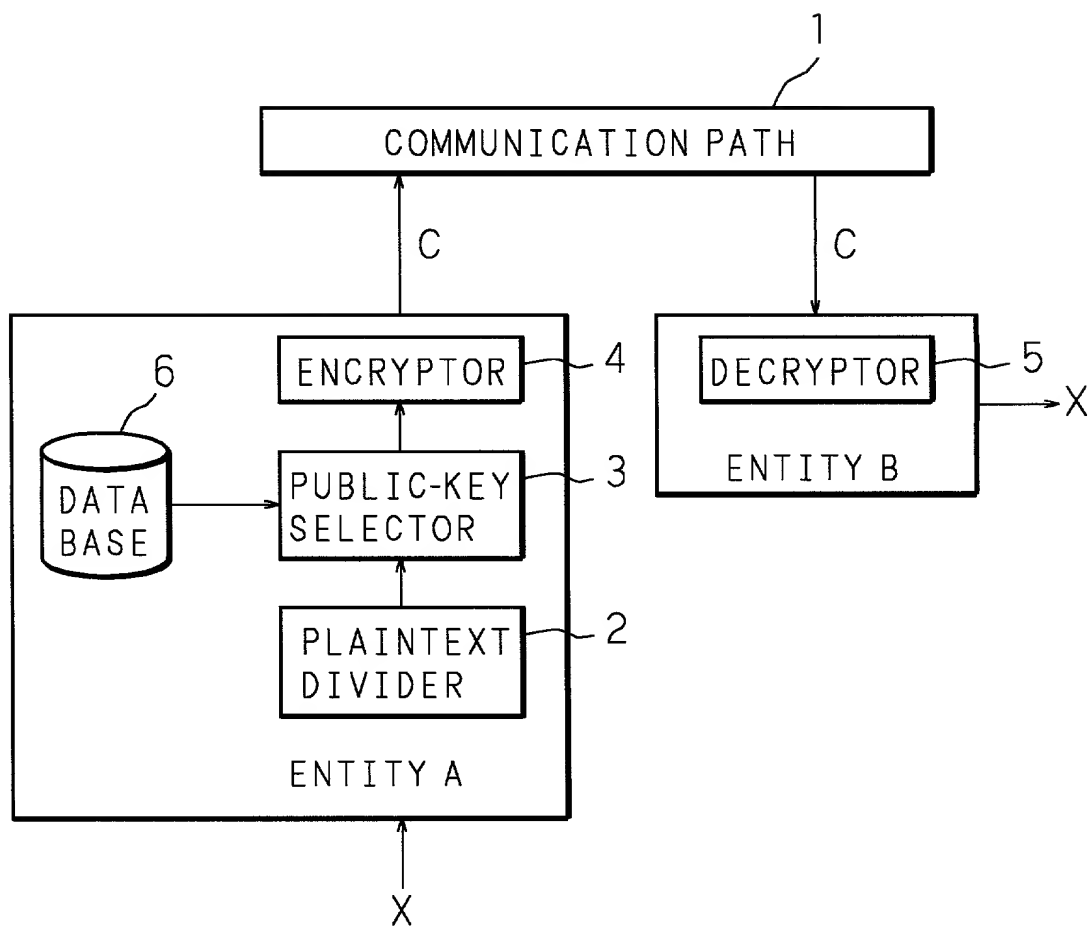
22. A computer data signal embodied in a carrier wave for transmitting a program, the program being configured to cause a computer to decrypt a ciphertext generated by using

a plurality of public keys selected in such a manner that one public key is selected for each of a plurality of s-bit divided plaintexts obtained by dividing a plaintext among 2^s (s: natural number) public keys which include therein a random number term and are prepared for each divided plaintext, according to bit data of each divided plaintext, comprising:

a code segment for causing the computer to sequentially decrypt the divided plaintexts while identifying the selected public keys.

00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

FIG. 2



CLASS 1	CLASS 2	CLASS 3	...	CLASS K
$v_1^{(0)} w_1$	$2 v_2^{(0)} w_1$	$2^2 v_3^{(0)} w_1$...	$2^{K-1} v_K^{(0)} w_1$
$v_1^{(1)} w_1$	$2 v_2^{(1)} w_1$	$2^2 v_3^{(1)} w_1$...	$2^{K-1} v_K^{(1)} w_1$

FIG. 4

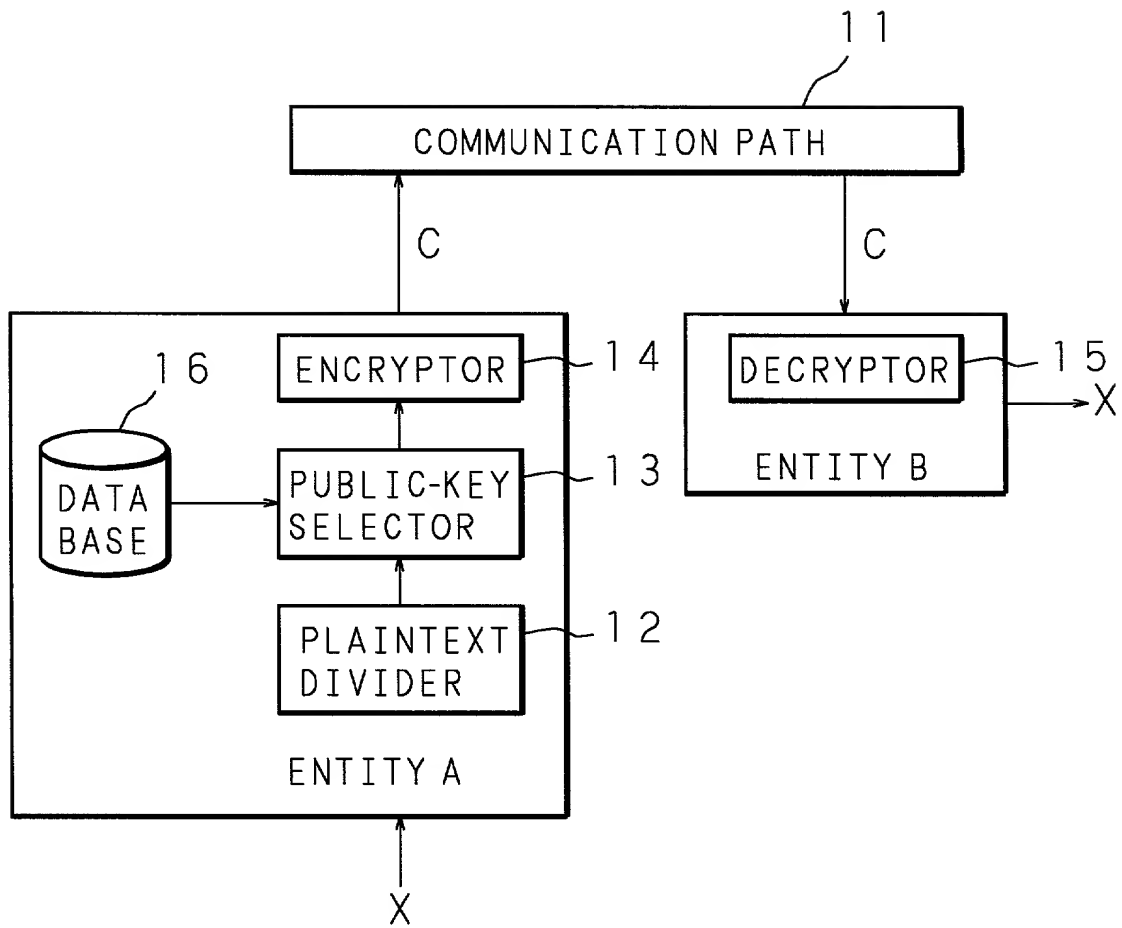
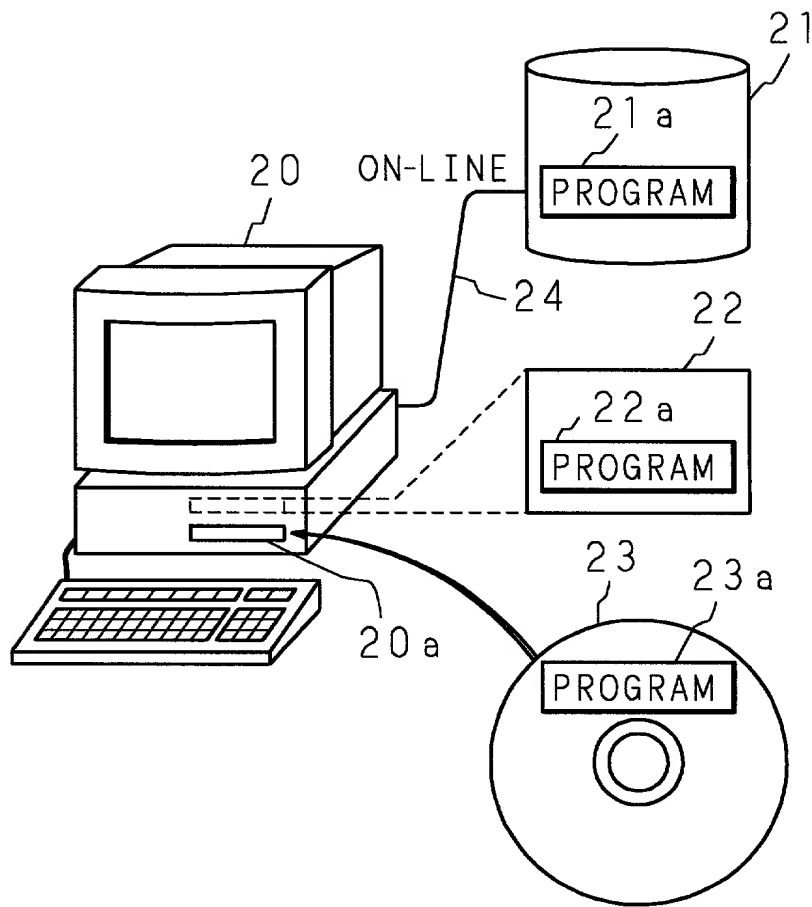


FIG. 5



DECLARATION
and POWER OF ATTORNEY☒ ORIGINAL
☐ CONTINUATION
☐ DIVISIONAL

As a below named inventor, I declare that the information given herein is true, that I believe that I am the original, first and sole inventor (if only one name is listed as 1 below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **ENCRYPTION METHOD, CRYPTOGRAPHIC COMMUNICATION METHOD, CIPHERTEXT GENERATING DEVICE AND CRYPTOGRAPHIC COMMUNICATION**

the specification of which is attached hereto unless the following box is checked

☐ was filed on _____ as United States Application Number or PCT International Application Number **SYSTEM OF PUBLIC-KEY CRYPTOSYSTEM**
and was amended on _____

My residence, post office address and citizenship are as stated below next to my name.

I acknowledge my duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations § 1.56(a). I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATION(S)

COUNTRY	APPLICATION NUMBER	DATE OF FILING Month Day Year	PRIORITY CLAIMED UNDER 35 U.S.C. 119
Japan	11-314372	11/4/1999	YES
Japan	11-314371	11/4/1999	YES

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.)

(Filing Date)

(Status)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or Agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

STUART LUBITZ, Reg. No. 20,680; LOUIS A. MOK, Reg. No. 22,585; JOHN P. SCHERLACHER, Reg. No. 23,009; WILLIAM H. WRIGHT, Reg. No. 36,312; DAVID LUBITZ, Reg. No. 38,229; WEI-NING YANG, Reg. No. 38,690; ALFRED A. D'ANDREA, JR., Reg. No. 27,752; WILLIAM J. KUBIDA, Reg. No. 29,664; STUART T. LANGLEY, Reg. No. 33,940; MICHAEL BYORICK, Reg. No. 34,131; CAROL W. BURTON, Reg. No. 35,465; STEVEN C. PETERSON, Reg. No. 36,238; STEVEN K. BARTON, Reg. No. 36,445; SARAH S. O'ROURKE, Reg. No. 41,226; E. MATTHEW G. DYOR, Reg. No. 42,278.

Send correspondence to:

Hogan & Hartson L.L.P.
500 South Grand Avenue, Suite 1900
Los Angeles, California 90071

DIRECT TELEPHONE CALLS TO:

213-337-6700

(Please Print)

1	Name of Inventor Masao KASAHARA	Residence CITY Mino-shi	STATE or COUNTRY Osaka, Japan
	Post Office Address 15-3, Aogei 4-chome, Mino-shi, Osaka 562-0025, Japan		CITIZENSHIP Japanese
2	Name of Inventor Yasuyuki MURAKAMI	Residence CITY Kyoto-shi	STATE or COUNTRY Kyoto, Japan
	Post Office Address 39-13, Karahashi Nishihiragaki-cho, Minami-ku, Kyoto-shi, Kyoto 601-8468, Japan		CITIZENSHIP Japanese
3	Name of Inventor	Residence CITY	STATE or COUNTRY
	Post Office Address		CITIZENSHIP
4	Name of Inventor	Residence CITY	STATE or COUNTRY
	Post Office Address		CITIZENSHIP

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 1 <i>Masao Kasahara</i>	SIGNATURE OF INVENTOR 2 <i>Yasuyuki Murakami</i>
DATE October 23, 2000	DATE October 23, 2000
SIGNATURE OF INVENTOR 3	SIGNATURE OF INVENTOR 4
DATE	DATE